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Pu, Minhao; Hu, Hao; Ji, Hua; Galili, Michael; Oxenløwe, Leif Katsuo; Jeppesen, Palle; Hvam, Jørn Märcher; Yvind, Kresten

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Broadband Polarization-Insensitive Wavelength Conversion Based on Non-Degenerate Four-Wave Mixing in a Silicon Nanowire

M. Pu, H. Hu, H. Ji, M. Galili, L. K. Oxenløwe, P. Jeppesen, J. M. Hvam, and K. Yvind
DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Building 343, DK-2800 Lyngby, Denmark
mipu@fotonik.dtu.dk

Abstract: We experimentally demonstrate broadband polarization-insensitive one-to-two wavelength conversion of a 10-Gb/s DPSK data signal based on non-degenerate four-wave mixing in a silicon nanowire with bit-error rate measurements.
OCIS codes: (190.4380) Nonlinear optics, four-wave mixing; (190.4390) Nonlinear optics, integrated optics; (230.7370) Waveguide; (130.7405) Wavelength conversion devices.

1. Introduction

All-optical wavelength conversion (AOWC) may be an important functionality in future wavelength division multiplexing (WDM) networks. This functionality has been demonstrated in different devices including semiconductor optical amplifiers (SOAs) [1], periodically poled lithium niobate (PPLN) waveguides [2], and highly nonlinear fibers (HNLFs) [3], based on different nonlinear effects. Recently, nonlinear effects in silicon nanowires have attracted considerable research interests due to compactness, large conversion bandwidth and complementary metal-oxide-semiconductor (CMOS) compatibility. Due to the strong light confinement in silicon nanowires with sub-micron dimensions, the group velocity dispersion (GVD), which is a critical parameter for parametric processes, can be engineered, and thus one can achieve ultra-broadband wavelength conversion [4]-[6] based on four-wave mixing (FWM). The FWM process is normally highly polarization dependent and an efficient FWM process occurs when the input signal and pump waves are both aligned to either the transverse-electric (TE) mode or the transverse-magnetic (TM) mode. However, a polarization insensitive operation is desired since the state of polarization (SOP) of the input signal fluctuates with time and distance in a real transmission system. Previously, a polarization-insensitive FWM-based AOWC technique using an angled-pump scheme has been proposed [7]. However, it is challenging to realize a broadband polarization-insensitive conversion which requires simultaneous optimization of dispersion profiles of the silicon nanowire for both TE and TM polarizations. The conversion bandwidth can be enhanced if the dispersion requirements are relaxed by utilizing a dual-pump configuration [8], in which the two pumps have large frequency separation while the signal frequency is close to one of the pump frequencies. In this paper, we utilize a dual-pump scheme to experimentally demonstrate broadband polarization-insensitive AOWC of a 10-Gb/s differential phase-shift keying (DPSK) data signal based on non-degenerate FWM in a silicon nanowire. Error-free performance is achieved for the converted signals while the polarization of the input data signal is being scrambled.

2. Experiment

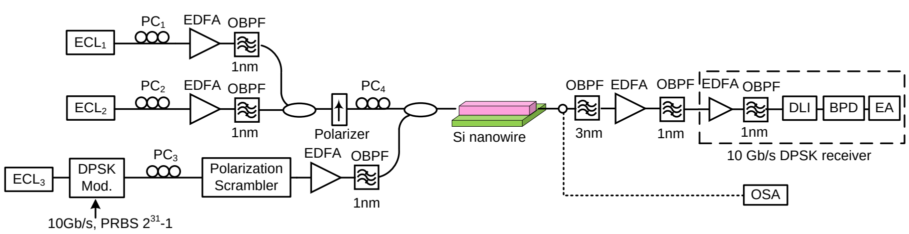

Fig. 1. Experimental setup for broadband polarization insensitive wavelength conversion of a 10-Gb/s DPSK data signal in a silicon nanowire.

The experimental setup for the broadband polarization-insensitive AOWC of a 10-Gb/s DPSK signal in a silicon nanowire is shown in Fig. 1. The pump waves are generated from two external cavity lasers (ECL_1 and ECL_2) at 1541.8 nm and 1579.8 nm, respectively. The signal wave, generated by ECL_3 at 1538.5 nm, is externally modulated by a Mach-Zehnder modulator (MZM) into a 10-Gb/s DPSK signal, encoded with a pseudo-random bit sequence (PRBS) of 2^{31}-1. All the pump and signal waves are amplified by erbium-doped fiber amplifiers (EDFAs), filtered by 1-nm optical band pass filters (OBPFs), and then combined by 3-dB couplers before coupling into the silicon nanowire. The polarization controller (PC) and polarizer are used to adjust the polarization angle for the pumps. The silicon nanowire is 1 cm long and its cross-sectional dimensions are 300×450 nm^2. The silicon nanowire was inversely tapered at both ends and covered by a polymer waveguide for efficient coupling [9]. Two tapered fibers are used for coupling light into and out from the silicon nanowire. At the output of the silicon nanowire, the converted signal (idler wave) is filtered out by two OBPFs, amplified by an EDFA in between, and detected by the 10-Gb/s DPSK receiver (shown by the dashed box in Fig. 1). In the receiver, the 10-Gb/s DPSK data signal is pre-amplified, filtered with a 1-nm OBPF and then decoded by a one-symbol delay interferometer (DLI). The output of the DLI is detected by a balanced photodetector (BPD), followed by a 10-Gb/s error analyzer (EA) for BER measurements. An optical spectrum analyzer (OSA) is used to measure the output spectrum.

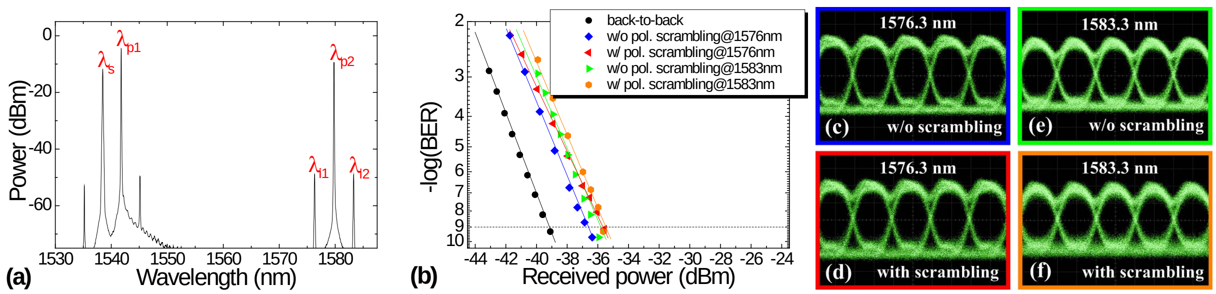

Fig. 2. (a) Measured optical spectrum at the output of the silicon nanowire. (b) BER measurement for the 10-Gb/s DPSK back-to-back signal and the converted signal without and with the input signal being polarization-scrambled. Measured eye diagrams for the converted signal without (c,e) and with (d,f) the input signal being polarization-scrambled.

Fig. 2 (a) shows the spectrum measured at the output of the silicon nanowire with the signal polarization scrambled. The two CW pump, signal and two idler waves are denoted λ_{p1}, λ_{p2}, λ_s, λ_{i1}, and λ_{i2}, respectively. The input powers of the two pumps and signal are 18.8 dBm, 16.6 dBm, and 9.5 dBm, respectively. Due to the non-degenerate FWM process, the signal is up-converted by 37 nm and 45 nm, to 1576.3 nm and 1583.3 nm, respectively. The conversion efficiency is around -37.1 dB. The polarizations of the pump waves were adjusted to minimize the signal distortion at the error analyzer while the polarization of the input signal is being scrambled. In this case, the conversion efficiency can be kept constant with different SOP of the input signal. To evaluate the performance of the converted data signal and the polarization insensitivity of the AOWC, we measured the BER for the 10-Gb/s DPSK back-to-back and the converted data signals without and with the signal polarization scrambling. As shown in Fig. 2 (b), error-free operations without an error floor were achieved for the converted signals without and with polarization scrambling. All the power penalties for the wavelength converted signal are less than 3.7 dB at the BER of 10^{-9} compared with the back-to-back case, which is mainly due to the residual CW pump and the relatively low optical signal-to-noise ratio (OSNR) of the converted signal. The receiver sensitivity difference for the signals in C- and L-bands also contributes to the power penalties. The receiver sensitivity for the converted idler signals could be improved by better filtering away the residual CW pump or increasing the pump power which would improve the conversion efficiency and result in an increased OSNR. On the other hand, the additional power penalties caused by the polarization scrambling of both idler signals are almost negligible (< 1 dB) and is partly due to the polarization dependent loss (PDL) in the 10-Gb/s receiver. Figs. 2 (c, d, e, f) show eye diagrams of the 10-Gb/s DPSK data signals without and with input signal polarization scrambling. It is seen that the wavelength converted signals in all the cases have clear and open eyes which are comfortably error free.

3. Conclusion

We have experimentally demonstrated broadband polarization-insensitive AOWC of a 10-Gb/s DPSK data signal. The polarization-insensitive operation is based on angled dual-pump non-degenerate FWM in a 1-cm long silicon nanowire. Error-free performance is achieved for the wavelength converted signal irrespective of the signal polarization scrambling being on or off. The residual polarization sensitivity is almost negligible (< 1 dB).

4. Reference

[1] C. M. Gallep, O. Raz, and H. J.S. Dorren, in Proc. OFC 2010, paper OWP2 (2010).
[2] H. Hu, R. Nouroozi, R. Ludwig, B. Huettl, C. Schmidt-Langhorst, H. Suche, W. Sohler and C. Schubert, Applied Physics B 101, 875-882 (2010).
[3] H. Hu, E. Palushani, M. Galili, H. C. H. Mulvad, A. Clausen, L. K. Oxenløwe, and P. Jeppesen, Opt. Express 18(10), 9961-9966 (2010).
[4] M. A. Foster, A. C. Turner, R. Salem, M. Lipson and A. L. Gaeta, Opt. Express 15(20), 12949 (2007).
[5] M. Pu, H. Hu, M. Galili, H. Ji, L.K. Oxenløwe, K. Yvind, P. Jeppesen, and J.M. Hvam, IEEE Photon. Technol. Lett. 23(19), 1409-1411 (2011).
[6] H. Hu, H. Ji, M. Galili, M. Pu H. C. H. Mulvad, L. K. Oxenløwe, K. Yvind, J. M. Hvam, and P. Jeppesen, Opt. Express, 19(21), 19886-19894 (2011).
[7] S. Gao, X. Zhang, Z. Li, and S. He, IEEE J. Sel. Topics Quantum Electron. 16(1), 250-256 (2010).
[8] S. Gao, E. Tien, Y. Huang, and S. He, Opt. Express, 18(26). 27885-27890 (2010).
[9] M. Pu, L. Liu, H. Ou, K. Yvind, and J. M. Hvam, Opt. Commun. 283, 3678-3682 (2010).